1879MNRAS..39..440D

so that we shall fall into no very great error if we take

$$\overset{\mathrm{h}}{1}\ \overset{\mathrm{m}}{5}\ \overset{\mathrm{s}}{21 \cdot 21}$$

for the difference of longitude between Greenwich and Vienna.

The reduction of the point of observation to the old University Observatory of Vienna is $+10^{\mathrm{s}}\cdot52$. For this latter point, therefore, the difference of longitude with respect to Greenwich amounts to $1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 31^{\mathrm{s}}\cdot73$, which agrees very well with the old (*Nautical Almanac*) value; i.e. $1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 31^{\mathrm{s}}\cdot9$.* In general it would appear that the old longitudes, obtained without telegraphic operations, are not so bad as is commonly supposed.

On the Coincidence of the Bright Lines of the Oxygen Spectrum with Bright Lines in the Solar Spectrum. By Henry Draper, Esq., M.D.

I intend in this paper to speak of the steps that led to the discovery of oxygen in the Sun, to describe very briefly some of the successive improvements of the electrical and optical apparatus employed, and finally to discuss the earlier results and to show their subsequent confirmation.

In 1857, after the meeting of the British Association at Dublin, some of the members, by the kindness of the Earl of Rosse, were invited to visit the 6-foot Reflector at Birr Castle. In this way I enjoyed the advantage of seeing the methods by which that great instrument had been produced, and, on returning to America in 1858, it prompted me to begin the construction of a metallic speculum of 15½ inches aperture. Soon after, by the advice of Sir John Herschel, who had early information of Foucault's work in Paris, the metal was abandoned in favour of silvered glass, and several mirrors were ground and polished. The telescope was constructed especially for photography, and good results were obtained in 1863, culminating in the production of a photograph of the Moon 50 inches in diameter. These were published in the *Smithsonian Contributions to Science* for the succeeding year. The success procured with this instrument prepared the way for making a silvered glass Equatoreal of 28 inches aperture, which was ready for use in 1871, though it has been much modified since. It was obvious that increased light-

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* *Note by Mr. Lynn.*—Until 1872 the *Nautical Almanac* has $1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 31^{\mathrm{s}}\cdot9$; from 1873, $1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 31^{\mathrm{s}}\cdot3$, adopted from the *Berliner Astronomisches Jahrbuch* for 1870. The former value was adopted from an investigation by Professor Littrow in 1824 (*Ast. Nach.* vol. iii. p. 64), based on observations of solar eclipses and occultations made about the end of the last century. It is worthy of notice that the result of the mean of six direct comparisons between Greenwich and Vienna there given (from two eclipses of the Sun in 1787 and 1788 and four occultations of stars in *Taurus* and *Gemini* in 1786, 1788, 1791, and 1792) is $1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 31^{\mathrm{s}}\cdot78$, closely agreeing with that of Dr. Oppolzer above.

1879MNRAS..39..440D

collecting power and precise equatoreal movements were necessary for the modern applications of physics to astronomy. More recently still there has been attached to the same equatoreal stand an achromatic telescope of 12 inches aperture made by Alvan Clark & Sons, this being particularly intended for solar spectroscopic work.

Soon after the 28-inch Reflector was turned to stellar and planetary photographic spectroscopy, it became evident that the results obtained required for their interpretation photographs of metallic and non-metallic spectra, so that comparisons might be instituted leading to precise knowledge of the elements producing lines at the more refrangible end of the spectrum. This led to a division of the work into two parts, one for the Observatory in the country in the warmer half of the year, the other for my town Laboratory during the winter. It was in the latter that most of the oxygen work has been done, and consequently the engine, the Gramme machine, the induction coil, and the large spectroscope are generally there.

My first photographs of metallic spectra were taken with such apparatus as happened to be at hand, viz. a couple of Bunsen's batteries, an induction coil giving a spark of ½ inch, and a Hofmann's direct-vision spectroscope. The length of the spectrum from G to H was about half an inch, but, though the dimensions were small, the promise was great. After some experiments, however, and after obtaining more powerful instrumental appliances, it seemed best, as able physicists were engaged on the metallic spectra, to turn attention more particularly to photographing the spectra of the non-metals. The exceedingly valuable researches of Dr. Huggins had brought the astronomical importance of nitrogen, carbon, and hydrogen into notice, and these accordingly were next the subject of experiment. Not long after, on examining a series of photographs of the fluted spectrum of nitrogen taken with juxtaposed solar spectra, the suspicion that there was a coincidence of some bright bands in the two spectra was suggested. On pursuing the subject with more and more powerful electrical and optical arrangements, the coincidence of bright lines of oxygen with bright lines in the solar spectrum was discovered.

The original apparatus, as has been said above, was on a very small scale, but it was soon replaced by a larger battery, a 2-inch induction coil, and a direct-vision prism of 1 inch aperture by Browning. The electrical part was made more and more powerful as the research proceeded, the 2-inch induction coil being succeeded by one of 6 inches, and that in turn by a Ruhmkorff coil capable of giving a spark of 17 inches. The battery was eventually superseded by a Gramme dynamo-electric machine which can produce a current powerful enough to give, between carbon points, a light equal to 500 standard candles. When this machine is properly applied to the 17-inch induction coil, it will readily give 1,000 10-inch sparks per

1879MNRAS..39..440D

minute. These, being condensed by 14 Leyden jars, communicate an intense incandescence to air, and light enough is produced to permit of the use of a narrow slit, and of a collimator and telescope of long focus.

Since 1877, when the first publication of the discovery of oxygen in the Sun was made, still further improvements, especially in the optical parts, have been completed, so that I am now enabled to photograph the oxygen spectrum with four times the dispersion then employed. For the sake of clearness, it is best to give a brief description: 1st of the electrical part, and 2nd of the optical part.

The electrical part consists of the Gramme machine and its driving engine, the induction coil, the Leyden jars, and the terminal or spark compressor. An advantage the Gramme has over a battery is in the uniformity of the current it gives when an uniform rate of rotation of its bobbin is kept up. Of course this implies the use of a prime mover that is well regulated. The petroleum engine of one-and-a-half horse-power which I have employed is convenient and safe, and does this duty well. As to the Gramme itself, it is only needful to call attention to a modification of the interior connections. In one form the bobbin of wire which revolves between the magnets is double, so that the current produced may be divided into two. Under ordinary circumstances, where the machine is used to produce light, both sides of the bobbin send their currents through the electro-magnets. But if the whole current be sent through a quick-working break-circuit into an induction coil, the electro-magnets do not become sufficiently magnetised to produce any appreciable effect. It is expedient, therefore, to arrange the connections so that one-half of the bobbin gives a continuous current through the electro-magnets and keeps up the intensity of the magnetic field, and then the current from the other half of the bobbin may be used for exterior work, whether continuous or interrupted.

At first a Foucault mercurial interruptor was arranged to make and break the current passing into the primary circuit of the induction coil; but during the past year, by carrying the rate of rotation of the Gramme up to 1,000 per minute, the strength of the current has been so much increased that the mercury was driven violently out of the cup, and hence it was essential to arrange a mechanical break in which solid metal alone was used. This has been accomplished by fastening on the axis of the Gramme bobbin a wheel with an interrupted rim, which serves the purpose well.

As to the induction coil, it is only needful to say that it gives a good thick spark, which is limited to 12 inches, to avoid the risk of injuring the insulation. The Leyden jars are 14 in number, having altogether 7 square feet of coating on each surface.

The arrangement of the terminals from the Leyden jars to get the steadiest and brightest effect has offered great difficulties.

1879MNRAS..39..440D

The condensed spark taken in the open air or in a gas under atmospheric pressure pursues, if unconfined, a zigzag course, and this is apt to produce a widening of the lines in the photographed spectrum. But, after many experiments, it turned out that the spark might be compressed between two plates of thick glass, or, better yet, between two plates of soapstone. If the interval between the plates was directed toward the slit of the spectroscope, the lateral flickering of the spark was prevented, and yet at the same time the spark was freely exposed to the slit without the intervention of glass or any substance on which the volatilised metal from the terminals could deposit. Very early in this research it had become apparent that Plücker's tubes could not be employed with electrical currents of more than a certain intensity, partly on account of the deposit that took place in the capillary portion, and partly because the terminals became so hot as to melt and crack the glass. Moreover, it was desirable to use one terminal of iron, so as to be sure that the spectrum of the gas was correctly adjusted to the solar spectrum, and this is impracticable with Plücker's tubes. An additional advantage arises from the soapstone plates, viz. the temperature of the small volume of air between the terminals is materially increased, and increased brightness results. I have tried the effect of warming the air by passing it through a coil of brass tube maintained at a bright red heat, but this does not seem to make any perceptible difference when the terminals are enclosed in the spark compressor.

Spark Compressor.

The optical part of my apparatus has undergone many modifications. At first a Hofmann direct-vision prism was combined with a lens of 6 inches focus; this was soon after replaced by a Browning direct-vision prism and a lens of 18 inches focus, the latter being arranged for conjugate foci, so that it was virtually as if collimating and observing lenses of 36 inches focus were employed. The final system, perfected this winter, consists of a collimator of 2 inches aperture and 26 inches focus, succeeded by two bisulphide of carbon prisms of 2 inches aperture and an observing or photographing lens of 6 feet 6 inches focal length. These prisms belong to Mr. Rutherfurd, and are the same he made for producing his celebrated solar prismatic spectrum. This gives a dispersion of about 8 inches between G and H, and enables me to get original negatives on a scale about half the size of Ångström's charts in the *Spectre Normal du Soleil.* When it is remembered that the light produced by the electric current in the spark compressor is scarcely equal to one standard candle, it will be realised that this great dispersion nearly attains the limit of present possibility. By comparison I have found, when the electric arc from this Gramme volatilises iron, the light is 60 times stronger than the most vivid incandescence of air that I have produced.

1879MNRAS..39..440D

The slit of the spectroscope is about one inch long, and opposite the lower half is placed a right-angled prism which serves to bring in a beam of sunlight from a heliostat. We thus have the solar spectrum and the air spectrum upon the plate at the same time, so that the two spectra on the negative are, strictly speaking, simultaneously produced. Moreover, by the aid of a magnifier we can ascertain, just previous to an exposure, whether the adjustments are in the best order. It is not commonly known that, to obtain the last degree of exactness in coincidence between a solar and an air spectrum, many precautions are necessary; and for this reason it is desirable to have iron vapour present at one of the poles, so as to determine the reliability of the coincidence by comparing iron in the spark spectrum with iron in the Sun.

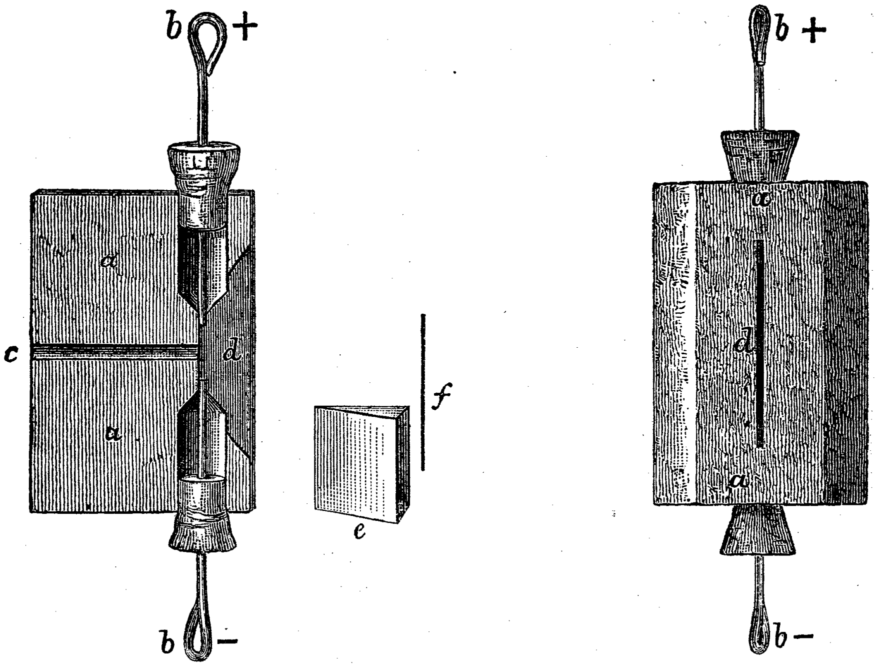

Fig. 1.
Section in plane of narrow opening.

Fig. 2.
Front view.

Spark Compressor.

a a	Soapstone.	*d*	Narrow opening to spark.
b b	Terminals.	*e*	Right-angled prism.
c	Aperture for introducing gases.	*f*	Slit of spectroscope.

Diagram of Photographic Spectroscope.

Having thus alluded to some of the principal peculiarities of the apparatus constructed for this research, it is proper in the next place to point out the nature of the evidence afforded by the photographs of the presence of oxygen in the Sun. The first

1879MNRAS..39..440D

photographs were on so small a scale that they did not even give rise to a suspicion of this fact, and it was not until 1876 that I felt sufficiently sure to make any publication. At this time the original negatives were about 2 inches long from G to H, and they bore an enlargement of three or four times quite well. The Albertype printed in 1877 in *Nature*, the *Comptes Rendus*, and the *American Journal of Science* was produced from such an enlargement. Since that time, in order to meet the criticism that perhaps the dispersion was not sufficient to disclose the lack of coincidence if such existed, I have increased the dispersion four times and am thus enabled to make enlarged photographs on a scale about twice the size of Ångström's chart. Enlargements of the juxtaposed spectra of air and Sun on this scale are now presented for inspection.*

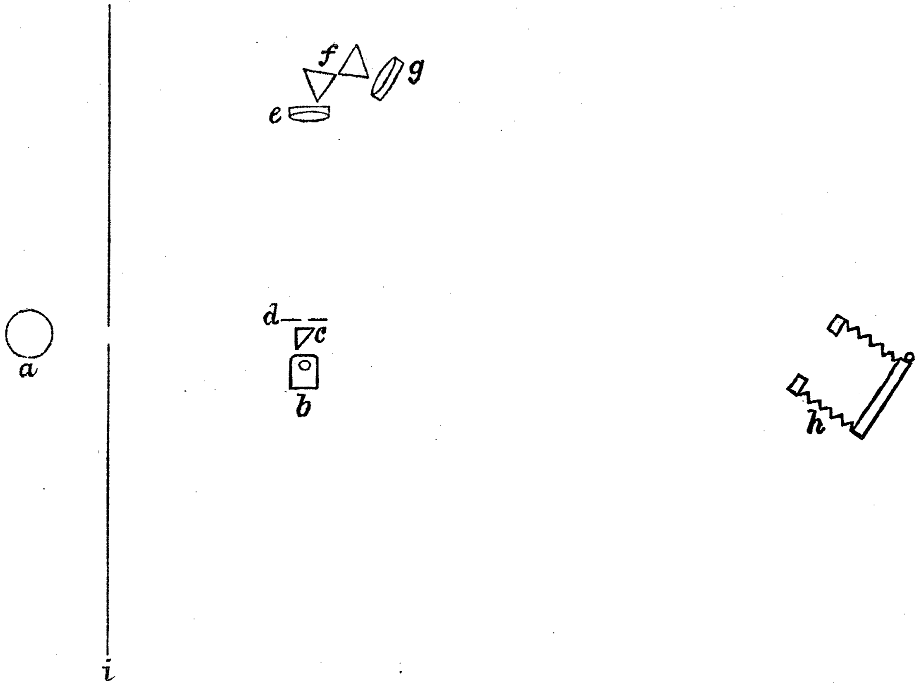

Fig. 3.

a Heliostat Mirror.
b Spark compressor.
c Right-angled prism.
d Slit.
e Collimator.
Two bisulphide prisms.
g Photographic objective.
h Camera.
i Window shutter.

Of course an enlargement never does justice to the original from which it was produced; and, in order to study the matter faithfully, the negative must be examined carefully with a magnifier. Beside this, owing partly to the fact that the solar spectrum has suffered from absorptive influences, both in the Earth's atmosphere and in the solar atmosphere, the conditions under which the oxygen spectrum is seen when compared with the spark spectrum are modified. In fact, a critical study of

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* These Enlargements were exhibited at the Meeting.—Ed.

1879MNRAS..39..440D

the two spectra demands that each line of oxygen should be separately photographed with the corresponding region of the Sun's spectrum, so as to reproduce as nearly as possible the same conditions for each. As an instance of the modifications which may be caused by the solar atmosphere, the superposition of absorption lines on the bright lines of oxygen may be mentioned. If, as seems to be the case, the stratum giving the oxygen spectrum in the Sun lies deeper than the reversing layer in which iron exists, I see no reason why an iron absorption line, for instance, may not fall upon an oxygen bright band. In support of this supposition that oxygen is photospheric, it may be stated that, though I have examined the chromosphere on many occasions, I have not as yet seen the bright oxygen lines project beyond the apparent limb of the Sun as observed in the spectroscope, although several of the chromosphere lines catalogued by Young were readily visible. On consulting with Professor Young, he expressed the opinion that the oxygen groups near G did not appear as bright lines in the chromosphere, even under the exceptionally favourable circumstances he enjoyed at Sherman. For the purpose of continuing the study of this point, and also of examining small areas on the Sun, faculæ, spots, &c., Alvan Clark & Sons are constructing for me a special spectroscope, which can give the dispersion of twenty heavy flint prisms and can bear high magnifying power.

If it be conceded that there are bright lines in the spectrum of the solar disk, and this seems to be the opinion of several physicists, especially Lockyer, Cornu, and Hennessy, the question of their origin naturally attracts attention. It seems that there is great probability, from general chemical reasons, that a number of the non-metals may exist in the Sun. The obvious continuation of this research is in that direction. But the subject is surrounded by exceedingly great obstacles, arising principally from the difficulty of matching the conditions as to temperature, pressure, &c. found in the Sun. Anyone who has studied nitrogen, sulphur, or carbon, and has observed the manner in which the spectrum changes by variations of heat and pressure, will realise that it is well-nigh impossible to hit upon the exact conditions under which such bodies exist at the level of the photosphere. The fact that oxygen, within a certain range of variation, suffers less change than others of the non-metals has been the secret of its detection in the Sun. It appears to have a greater stability of constitution, though Schuster has shown that its spectrum may be made to vary. I have already begun an extended series of experiments on the non-metals; but the results exhibit such confusion that their bearing cannot at present be distinctly seen. In the case of nitrogen the broad bands between G and H exhibit, under the most intense incandescence, a tendency to condense into narrow bands or lines, and indeed there are some sharp lines of nitrogen in the photographs now presented.

1879MNRAS..39..447P

It does not follow, therefore, that the bright-bands of oxygen are necessarily the brightest parts of the solar spectrum. Other substances may produce lines or bands of greater brilliancy.

There is also another cause for a difference of appearance in a bright-line spectrum produced in a laboratory and bright lines in the Sun. While the edges of a band in the spark spectrum may be nebulous or shaded off, the corresponding band in the solar spectrum may have its edges sharpened by the action of adjacent dark lines due to one or another of the metallic substances in the Sun.

On the whole, it does not seem improper for me to take the ground that, having shown by photographs that the bright lines of the oxygen spark spectrum all fall opposite bright portions of the solar spectrum, I have established the probability of the existence of oxygen in the Sun. Causes that can modify in some measure the character of the bright bands of the solar spectrum obviously exist in the Sun, and these, it may be inferred, exert influence enough to account for such minor differences as may be detected.

In closing, it may be well to give some idea of the amount of labour and time this research has already consumed, and this cannot be better done than by a statement of the production of electrical action that has been necessary. Each photograph demands an exposure of 15 minutes, and, with preparation and development, at least half an hour is needed. The making of a photograph, exclusive of intermediate trials, requires, therefore, about 30,000 10-inch sparks, that is 30,000 revolutions of the bobbin of the Gramme machine. In the last three years the Gramme has made 20 millions of revolutions. The petroleum engine only consumes a couple of drops of oil at each stroke, and yet it has used up about 150 gallons. Each drop of oil produces two or three 10-inch sparks. It must also be borne in mind that comparison spectra can only be made when the Sun is shining, and clouds therefore are a fertile source of loss of time.

London, June 10, 1879.

On the Photographic Semi-diameter of the Moon.

By Professor C. Pritchard.

In the course of measuring the Lunar Photographs which have been obtained in the Oxford University Observatory by means of the De La Rue Reflector of 13 inches aperture, it occurred to me, for the purposes simply of acquiring confidence or otherwise in the laborious processes which have been undertaken, to compare the mean semi-diameter of the Moon thereby obtained with the mean semi-diameter adopted in the *Nautical Almanac*; and also to compare the photographic results with